Top 2012

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Physics of the interplay between the top quark and the Higgs

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Outline

- Top-Higgs interplay in the Standard Model
- Which story is the Higgs telling?
- What if the $\gamma\gamma$ excess is real?
- Higgs-top interplay in composite Higgs models
- Testing Higgs-top interplay in CHM
- $Ht\bar{t}$ in composite Higgs models
- Summary

Top-Higgs interplay in the SM

- Higgs mass predicted in the SM from EWPO (very sensitive to the top mass) **Erler, 1209.3324**

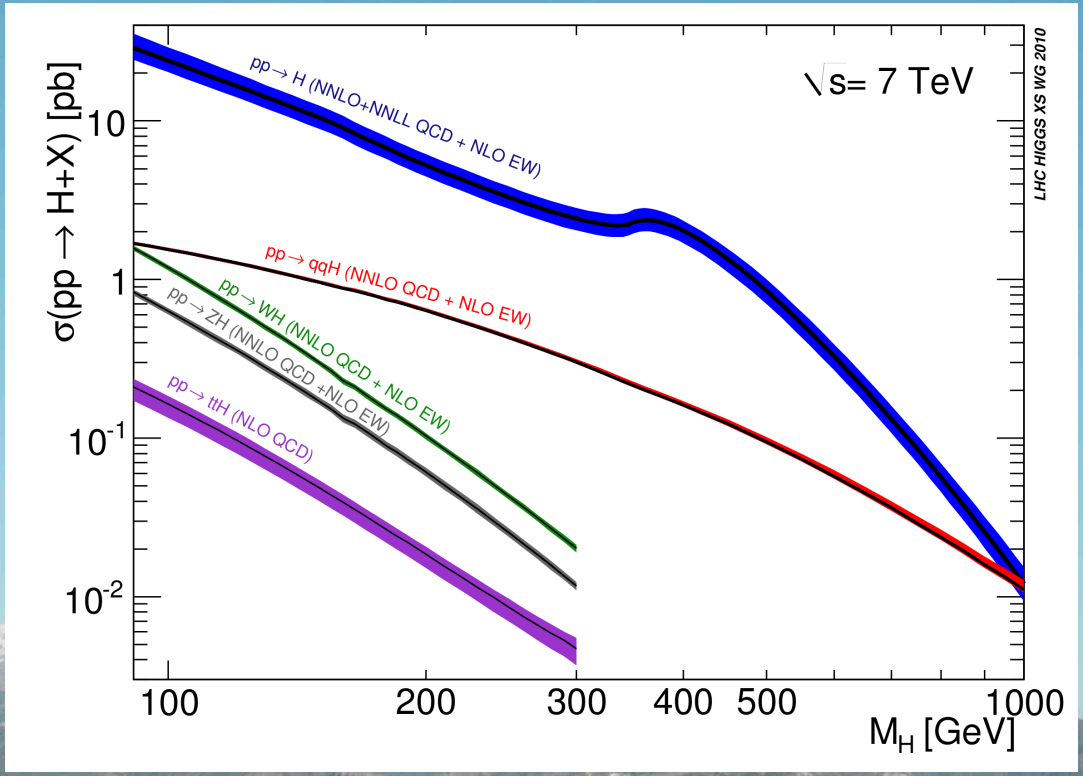
$m_H = 102 \pm {}^{24}_{20}\ \mathrm{GeV}$ $\quad$ $m_t = 173.2 \pm 1.0\ \mathrm{GeV}$

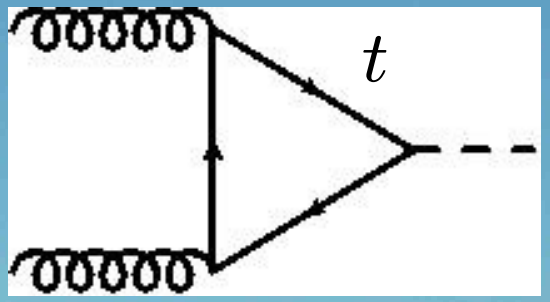
$m_H = 81 \pm {}^{32}_{24}\ \mathrm{GeV}$ $\quad$ $m_t = 169.6 \pm 3.5\ \mathrm{GeV}$

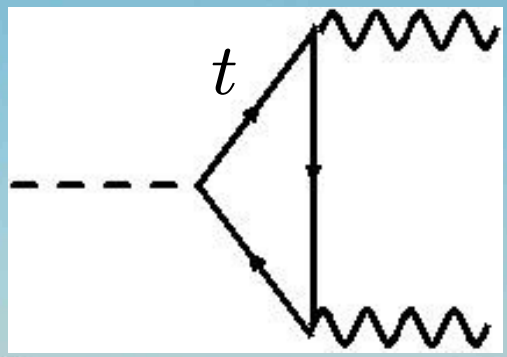
Very good agreement with direct searches

Top-Higgs interplay in the SM

- Higgs mass predicted in the SM from EWPO (very sensitive to the top mass)
- The top quark is crucial in Higgs production … and decay

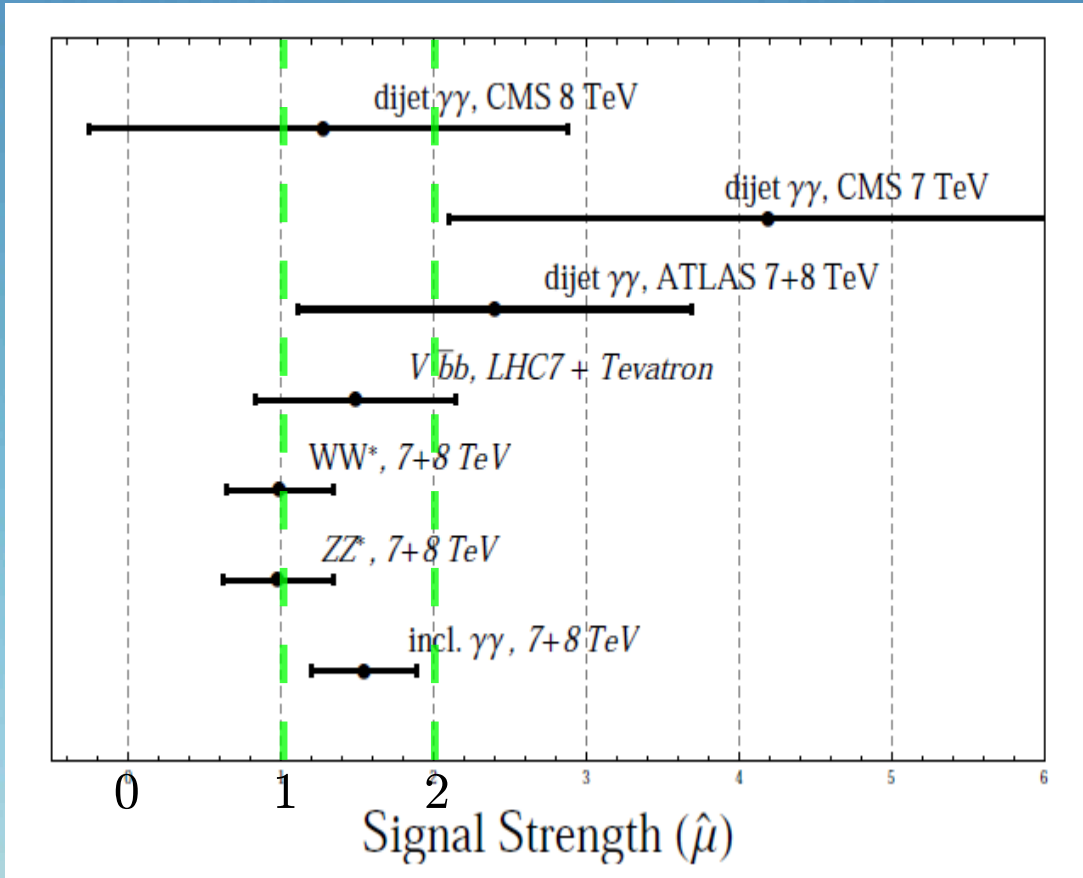






Which story is the Higgs telling?

- Latest results on Higgs searches

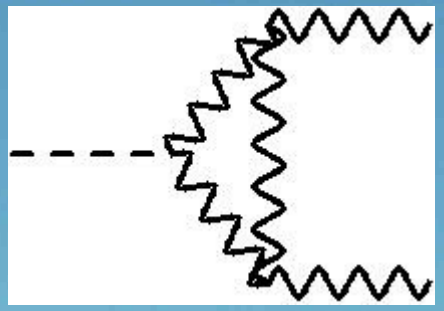


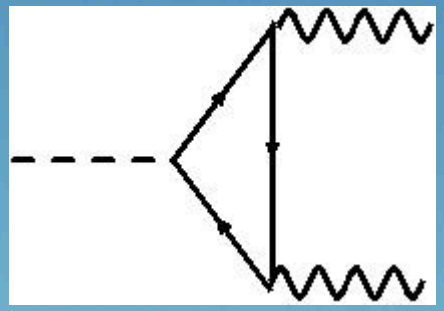
- $m_H \approx 125\ \mathrm{GeV}$
- VV and bb in good agreement with SM
- $\gamma\gamma \sim 1.5 - 2$ too large

Carmi, Falkowski, Kuflik, Volansky, Zupan 1207.1718

What if the $\gamma\gamma$ excess is real?

- Can we double $\Gamma_{H\to\gamma\gamma}$ without changing the production cross section or $\Gamma_{H\to VV,\bar{f}f}$?





- New contribution from uncolored particles running in the loop (or else $gg \to H$ modified)

Can be done but it's strongly constrained!

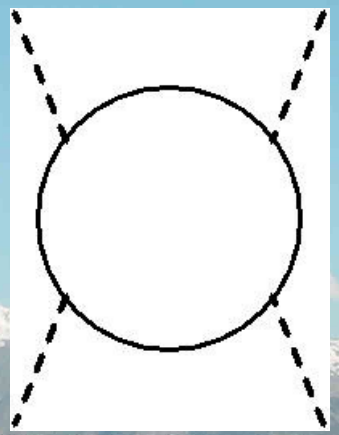
Carena, Low, Wagner 1206.1082

Arkani-Hamed, Blum, D'Agnolo, Fan 1207.4482

What if the $\gamma\gamma$ excess is real?

- Can we double $\Gamma_{H\to\gamma\gamma}$ without changing the production cross section or $\Gamma_{H\to VV,\bar{f}f}$?
  - New contribution from uncolored particles running in the loop (or else $gg \to H$ modified)
    - Need very light (~ few hundred GeV) particles with large Yukawa couplings
    - Can render λ negative through RGE or threshold effects or be excluded by direct searches

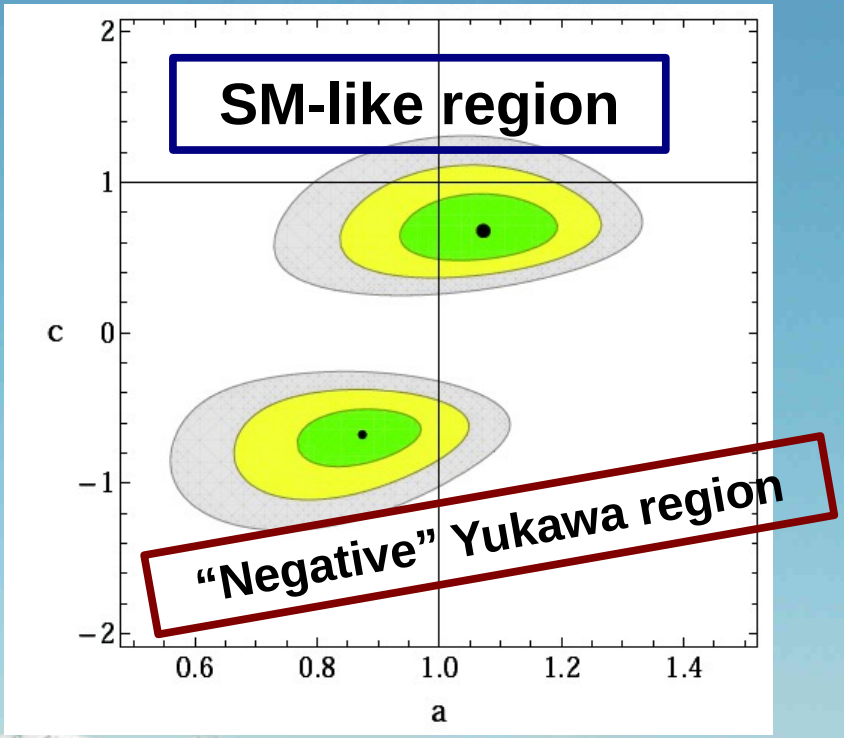
Arkani-Hamed, Blum, D'Agnolo, Fan 1207.4482; Reece 1208.1765



$$\frac{d\lambda}{dt} = -\frac{3}{8\pi^2}y^4 + \dots$$

What if the $\gamma\gamma$ excess is real?

- Can we double $\Gamma_{H\to\gamma\gamma}$ without changing the production cross section or $\Gamma_{H\to VV,\bar{f}f}$?
  - We can also do it with just tree level corrections



$$g_{HVV} = a \times g^{\rm SM}_{HVV}$$

$$g_{Hff} = c \times g^{\rm SM}_{Hff}$$

Espinosa, Grojean, Muhlleitner, Trott 1207.1717 see also Azatov, Contino, Galloway 1206.3171; Corbett, Eboli, González-Fraile, González-García 1207.1344; Giardino, Kannike, Raidal, Strumia 1207.1347; Montull, Riva 1207.1716; Carmi, Falkowski, Kuflik, Volansky, Zupan 1207.1718

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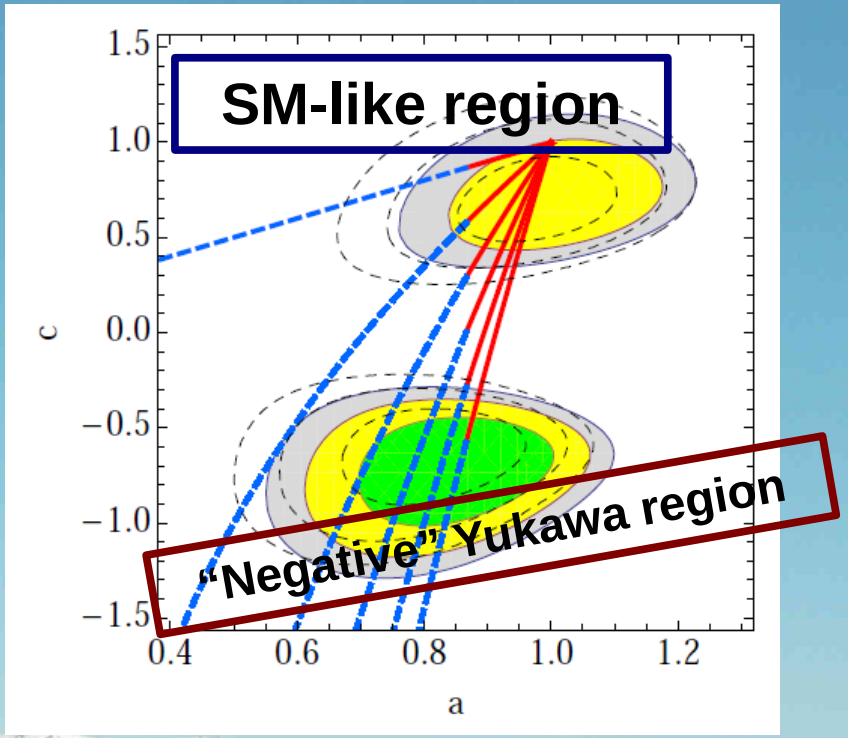


Can be realized in composite Higgs models with partial compositeness!

Montull, Riva 1207.1716;
see also Pomarol, Riva 1205.6434;
Chala, Grojean, Santiago in progress

- How do we avoid new loop corrections and Higgs quartic instabilities?

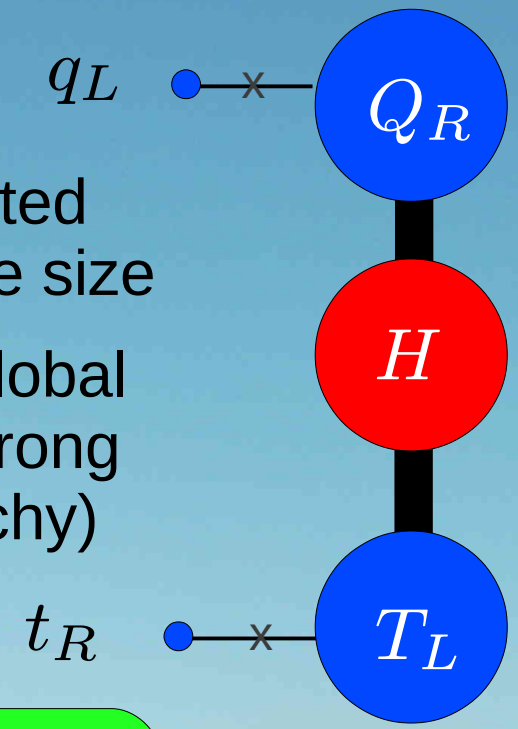
Composite Higgs and Partial Compositeness

Composite Higgs

Georgi, Kaplan, et al. 84-85

Higgs mass protected from UV by its finite size

It is a pNGB of a global symmetry of the strong sector (little hierarchy)



Many properties fixed by the symmetries!

Partial Compositeness

Kaplan 91

Contino, Kramer, Son, Sundrum 06

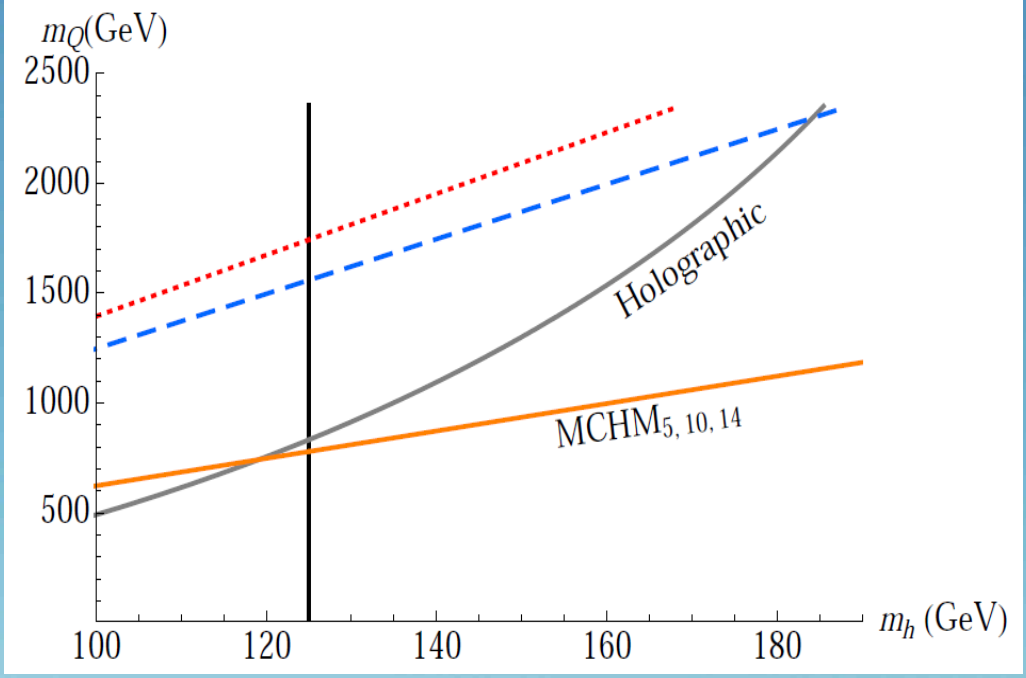
SM: elementary states external to the strong sector

Linear coupling: degree of compositeness

Large top mass: top is also composite!

Higgs-top interplay in CHM

- Light Higgs: top partners below the TeV scale

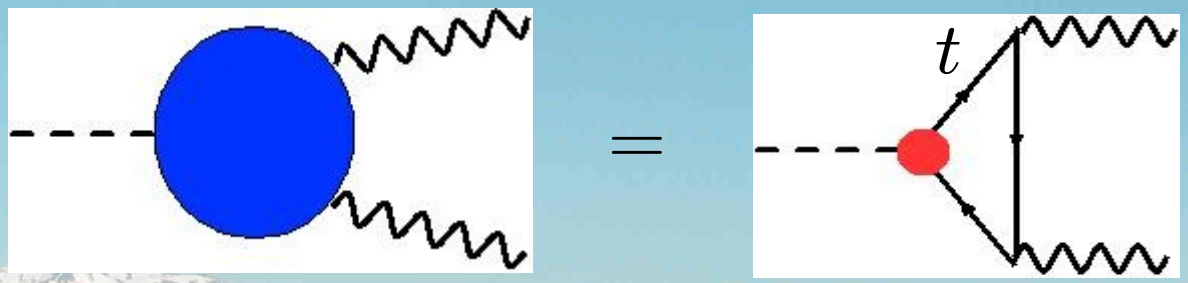


Top partners: New vector-like quarks related to the top by the symmetries of the strong sector

Pomarol, Riva 1205.6434
see also Matsedonskyi, Panico, Wulzer 1204.6333; Redi, Tesi 1205.0232; Marzocca, Serone, Shu 1205.0770

Higgs-top interplay in CHM

- Light Higgs: top partners below the TeV scale
- Why no large loop corrections?
  - Top Yukawa receives two types of corrections:
    - From non-linear Higgs effects: fixed by symmetry
    - From mixing with top partners: spectrum dependent
- In some cases, symmetry guarantees that only the first one contributes to $H \to gg, \gamma\gamma$ **Azatov, Galloway 1110.5646**



Higgs-top interplay in CHM

- Light Higgs: top partners below the TeV scale
- Why no large loop corrections?
  - Top Yukawa receives two types of corrections:
    - From non-linear Higgs effects: fixed by symmetry
    - From mixing with top partners: spectrum dependent
- Why no Higgs quartic instability?
  - RGE of λ subleading in the large N expansion
  - It takes longer to become negative, reaching the natural cut-off of the theory (strong coupling) before becoming unstable

Higgs-top interplay in CHM

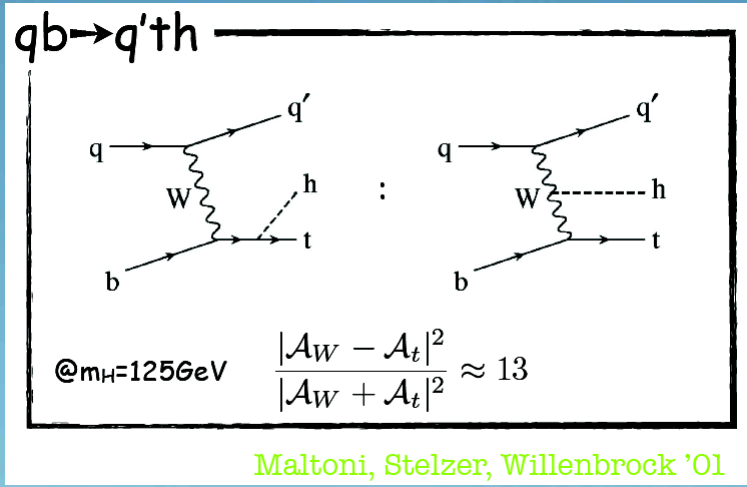
- Interesting situation
  - $\lambda_t \sim -1$ as effectively measured from $H \to gg, \gamma\gamma$ and determined purely from symmetry
  - Real λ_t can be quite different from -1, with the differences giving information on the spectrum

It is crucial to measure the top Yukawa coupling from tree level processes!

Measuring the top Yukawa coupling

- $pp \to Hqt$: sensitive to the sign of λ_t
  - Very difficult at the LHC

Farina, Grojean, Maltoni, Salvioni, Thamm, in progress



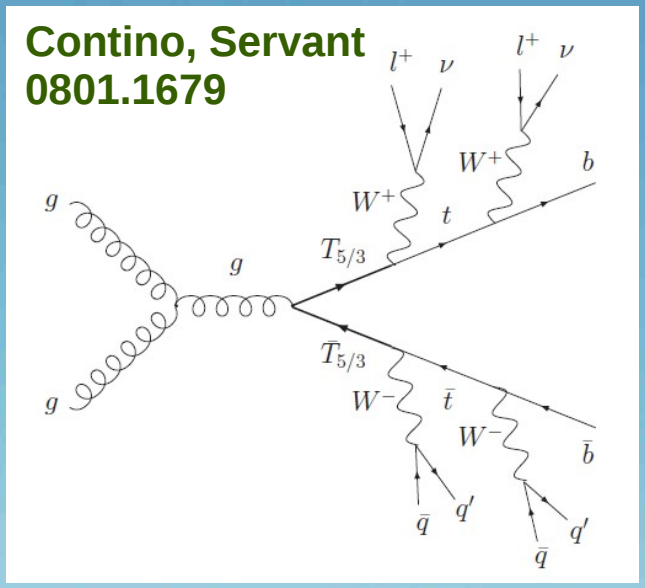
- $pp \to Ht\bar{t}$: measurement of the magnitude
  - Difficult but not impossible at LHC
  - Possible contamination from new physics

Plehn, Salam, Spannowsky 0910.5472

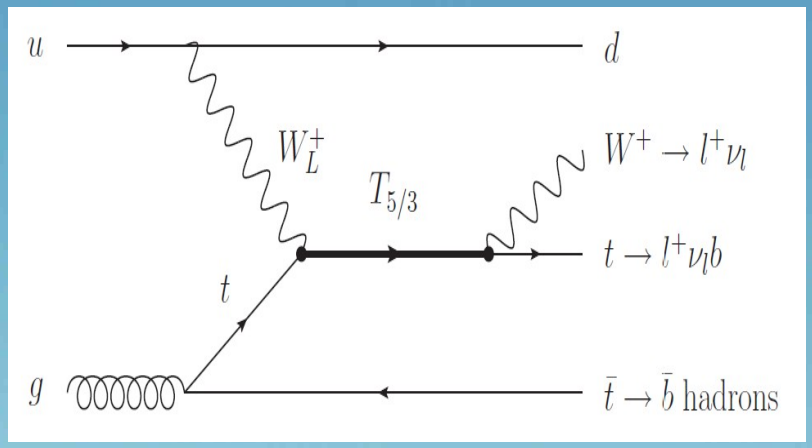
Finding hints elsewhere

- Can we test the mechanism elsewhere?
  - Look for the top partners themselves in pair or single production

Contino, Servant 0801.1679



Mrazek, Wulzer 0909.3977



- Excellent reach if light, can be tested up to $M \sim 1.5$ TeV

See also Aguilar-Saavedra 0907.3155; Dissertori, Furlan, Moorgat, Nef 1005.4414

Finding hints elsewhere

- Can we test the mechanism elsewhere?
  - Look for the top partners themselves in pair or single production
  - Look for anomalous (gauge) top couplings
    - Top partners also induce corrections to top gauge couplings **Aguila, Pérez-Victoria, Santiago ph/0007316**
  - Look for new Higgs production mechanisms:

$$pp \to G \to \bar{t}T \to H\bar{t}t$$ **Carmona, Chala, Santiago 1205.2378**

$$pp \to T\bar{T} \to Ht + X$$ **Aguila et al '89-90; Aguilar-Saavedra ph/0603200; Kribs, Martin, Roy 1012.2866; Azatov et al 1204.0455**

$$pp \to T\bar{b} \to Ht\bar{b}$$ **Vignaroli 1207.0830**

$Ht\bar{t}$ in Composite Higgs Models

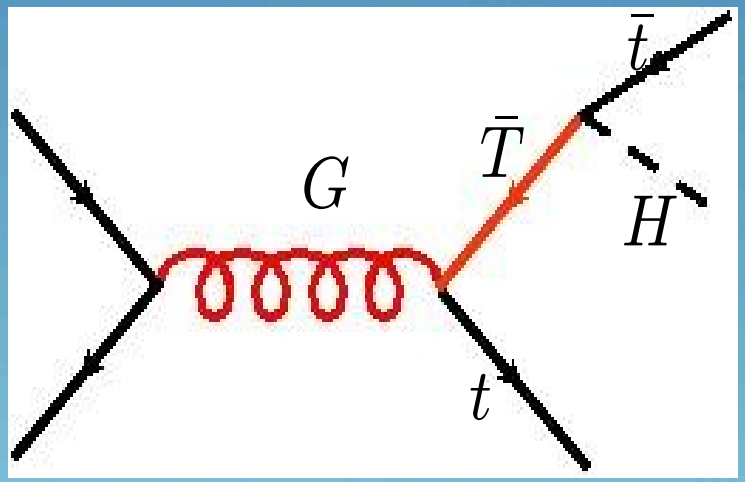
Carmona, Chala, Santiago 1205.2378

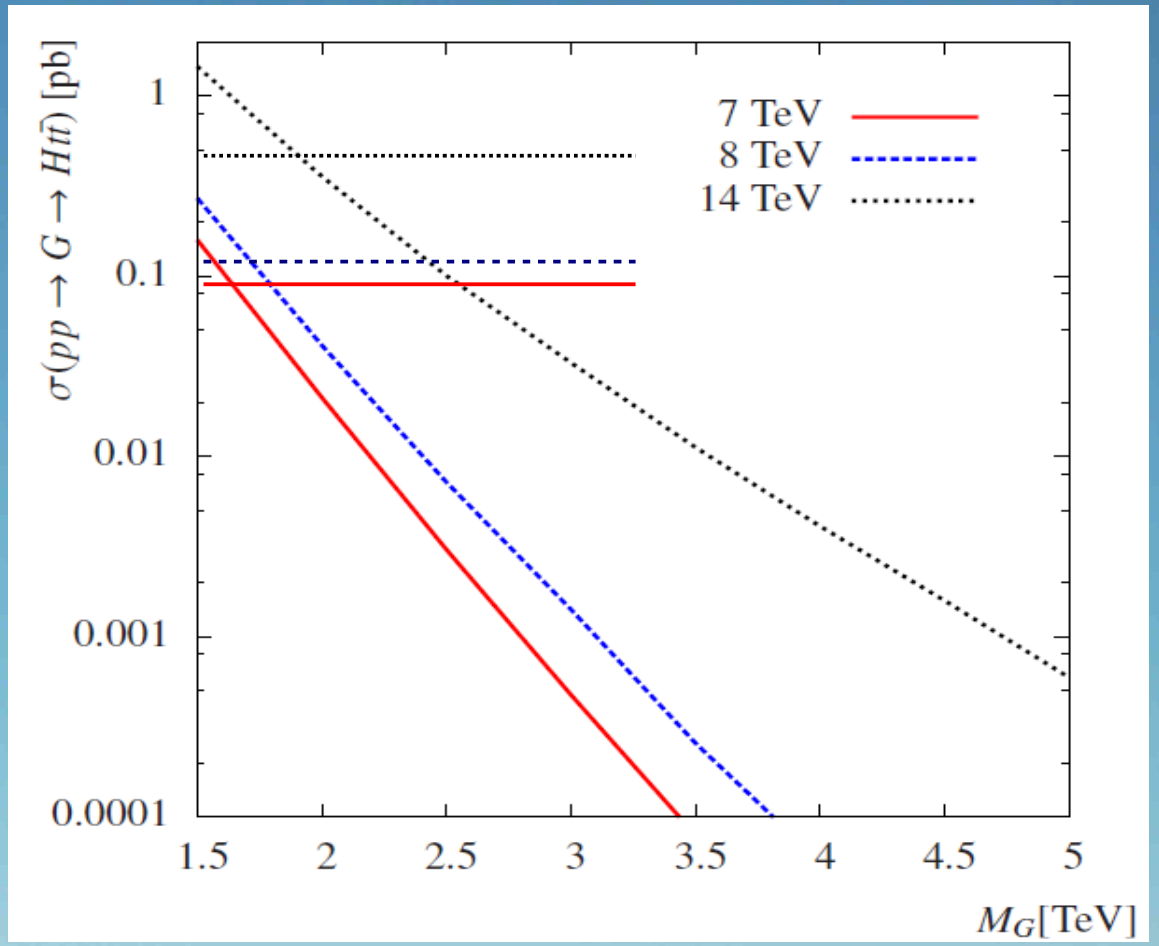
- Light composite Higgs implies light top partners
- Partial compositeness implies color octet vector resonances G (heavy gluons)
- New $Ht\bar{t}$ production mechanism: Single production of top partners through s-channel exchange of G in association with a t with decay into H t

$$pp \to G \to T\bar{t} \to Ht\bar{t}$$

- Reasonable x-section + distinctive kinematics

$Ht\bar{t}$ in Composite Higgs Models





$Ht\bar{t}$ in Composite Higgs Models

Carmona, Chala, Santiago 1205.2378

- Simulation
  - Madgraph/ALPGEN + Pythia + Delphes
  - Backgrounds considered

Process	LHC7 σ [pb]	LHC8 σ [pb]	LHC14 σ [pb]
$t\bar{t}$+0-4 jets (semileptonic+leptonic)	47.9	70.47	268.55
$t\bar{t}b\bar{b}$	0.09	0.15	0.85
Z+1-4 jets (leptonic)	530.5	641	1423
WW + 0-2 jets (semileptonic+leptonic)	15	22.6	49
W+1-2 jets ($p_T > 150$ GeV, leptonic)	–	–	84.9
W+1-4 jets (leptonic)	5133	6489	–

- Statistical estimator

$$\mathcal{S}(s,b) = \sqrt{2 \times \left[(s+b) \ln\left(1 + \frac{s}{b}\right) - s \right]}$$

$Ht\bar{t}$ in Composite Higgs Models

Carmona, Chala, Santiago 1205.2378

- Strategy
  - Use the leading $H \to b\bar{b}$ decay and semileptonic top decays

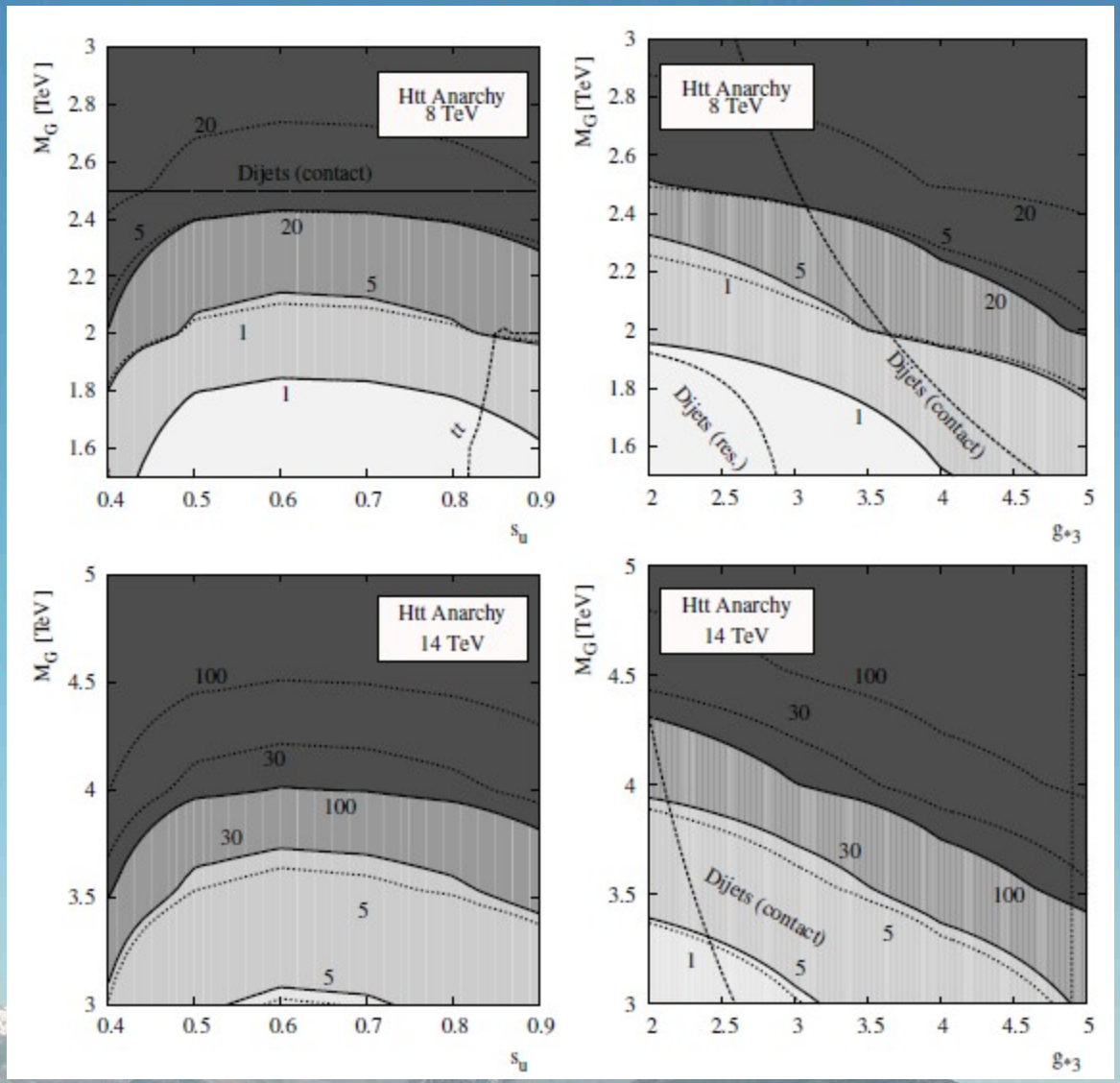
$$pp \to G \to T\bar{t} + \bar{T}t \to Ht\bar{t} \to 4b + 2j + l + \not{E}_T$$

  - Use b-tags and S_T as main discriminating variables
  - Use boosted top and Higgs techniques for larger masses

$Ht\bar{t}$ in Composite Higgs Models

Carmona, Chala, Santiago 1205.2378

- Results



Summary

- Higgs and top are intimately related in the SM and beyond
- Current Higgs results could be explained by anomalous top Yukawa coupling
- This scenario can be realized and tested in composite Higgs models
- $Ht\bar{t}$ is a crucial test of the scenario:
  - SM motivated cuts give information on λ_t
  - CHM motivated cuts give information on the spectrum